Demand forecasting

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Impact of Climate Change on Water Demand

Making informed planning decisions for demand forecasting

L Uthayakumaran, F Spanninks, A Barker, A Pitman, J Evans

ABSTRACT

Climate change impacts weather and changes in weather is the single largest factor influencing fluctuations in water demand. Therefore, it would be natural to expect climate change to impact on demand. However, most climate models typically do not produce a single forecast, but rather produce an ensemble of equally likely scenarios. The high variation between these projections lead to different estimates of demand, leaving decision makers with the task of selecting one projection to use. On the other hand, there exists no scientific way of doing this, as they are all equally likely, meaning selecting one would be as good as the other. This paper describes the way Sydney Water approached the problem, which was to use a two-staged process. This meant developing a mathematical solution to integrate the output of global models with Sydney Water's demand forecasting model, and developing an approach based on the risk tolerance thresholds of the decision it informs to select the most appropriate output from a climate model.

Keywords: Climate Change, Weather, Water Demand, Resilience, Modelling

INTRODUCTION

Weather is the single most significant factor that influences day-to-day variations in water demand. Weather driven variations in demand in Sydney are estimated to be as high as 50 GL; most of which is the result of extreme weather conditions such as heat waves and droughts, which are predicted to increase in severity and frequency with climate change. In 2016, Sydney Water entered into a research partnership with the University of New South Wales' Centre for Climate Change to bring together the expertise, knowledge and resources of both organisations, and develop a method of quantifying the impact of climate change on demand. As a result of this, Sydney Water has now developed an approach to successfully integrate the effect climate change has on demand forecasts, and for the first time has incorporated this into pricing recommendations made to the Independent Pricing and Regulatory Tribunal and other infrastructure planning initiatives such the Metropolitan water planning process. For a complete technical explanation of the methodology refer to Barker, et al (2018a).

This paper develops on work done to estimate the impact of climate change on demand in other cities, and previous estimates for Sydney at a less detailed level.

The methodology used here involves integrating a mathematical demand forecast model developed by Sydney Water with climate projections of the New South Wales / Australian Capital Territory Regional Climate Modelling (NARCLiM) via a Stochastic Weather Generator developed by the University of New South Wales. In addition to the interactive effect of the predictor variables including population growth, the dwelling type mix and climate change, the integrated model estimates the marginal impact of each of these factors on water demand. Thus, it is also possible to quantify the relative impact of climate change in comparison to population growth and dwelling type mix.

The purpose of this paper is to give an overview of the approach and how some of the challenges in integrating science with policy development were overcome.

The key challenges involved in estimating the impact of climate change on long-term demand are:

- Climate models typically predict averages, whereas demand is mostly driven by extreme events (severity and frequency)
- Climate Models (NARCLiM) do not produce a single projection, but generate 12 member ensembles, based on:
  - four climate models and,
  - three downscaling methodologies
- The difficulty of estimating the uncertainty surrounding secondary impacts (e.g., demand driven by the use of water in mitigation programs such as urban cooling).

The first challenge is overcome by building a 'weather generator' which develops Monte-Carlo simulations of weather scenarios based on climate average projections of NARCLiM, and integrating the weather generator with Sydney Water's demand model to produce demand forecasts taking climate change into account.

The second has more to do with decision making than science. The challenge here is to have the right decision-making framework for incorporating climate change into government decision-making and policy development. We propose a risk-based approach, selecting an ensemble member of the model, based on the risk tolerance profile of the decision it informs.

We point out that secondary impacts of climate change on demand (likely to be mainly constituted by demand from outdoor irrigation, greening and urban cooling) have not been properly estimated at this stage and are out of the scope of this paper.

SIMULATION/EXPERIMENT

The scientific component involves integrating the NARCLiM projections with the Sydney Water Consumption Model (SWCM) by developing a series of weather scenarios using a Stochastic Weather Generator and using them as inputs to SWCM.

Sydney Water Consumption Model

The Sydney Water Consumption Model is a statistical-forecasting-model based on dynamic panel regression methodology (Woolridge, 2010; Bun and Sarafidis, 2015) and the approch of Abrahams et al (2012). The model forecasts metered water use – which constitutes 90% of all consumption (the rest is either leakage or undermetered usage, which amounts to approximately 57 GL a year) – based on population change, dwelling types, whether or not a property has water efficiency programs such as BASIX, and five weather variables, which are:

1. average daily precipitation,
2. number of days in a month when precipitation exceeds 2mm,
3. average daily maximum temperature,
4. number of days in a month when temperature exceeds 300^{0}C
5. average daily pan evaporation.

Historic recordings from 12 weather stations operated by the Bureau of Meteorology were used in developing the model. For full technical details of the SWCM, please refer to Barker et al (2018a).

New South Wales / Australian Capital Territory Regional Climate Modelling Project (NARCLiM)

The NARCLiM project provides temperature and precipitation data based on four different Global Climate Models (GCMs) for the present (1990-2010), near-future (2020-2040) and far-future (2060-2080). The GCMs used are CCCMA3.1, CSIRO MK 3.0, ECHAM5 and MIROC 3.2. All simulations were based on SRES A2 emission scenarios. Data is available on 10 km x 10 km grids for the whole of Eastern Australia including Sydney Water's areas of operation. Three runs are produced for each period/GCM, with each run generated using different physics assumptions for the downscaling process.

The NARCliM data was bias corrected so that the temperature and precipitation have the same yearly averages as the Australian Water Availabilty Project (AWAP) data over the same period.

Stochastic Weather Generator

A stochastic weather generator developed by Barker et al (2018a) was used for the generation of weather scenarios as inputs for the SWCM. A weather generator was used to overcome the problem that each NARCliM member only produces a single realisation of a stochastic process (i.e.

weather). The weather generator enables multiple (in this case 100) realisations to be generated, each consistent with a NARCliM ensemble member, to examine the statistical distribution of weather and water consumption forecasts.

For each period/GCM/run combination, the stochastic weather generator was calibrated to produce weather scenarios with statistical properties similar to those of the NARCliM data. NARCliM weather data from the closest grid point to each of the 12 weather stations was used to calibrate the stochastic weather generator. Each weather scenario contains data for the 11 financial years from 2014/15 to 2024/25 and 100 weather scenarios were generated for each period/climate model/run combination.

In total, 13 sets of 200 years of data were generated for each time period (present, near future, far future) allowing quantification of the variance due to changing weather. All weather variables were assumed not to have a yearly trend within the 20 year NARCliM period. It should be noted that estimates of water demand by SWCM requires pan evaporation, a variable not generated by most weather and climate models including the NARCliM project. Instead, the evaporation model described by Barker et al (2018a) was used to generate evaporation data as a function of precipitation and maximum temperature.

The output from this was used as the five weather-related inputs to the SWCM.

Experiments performed

The consumption forecast generated through the above reflects changes in population, dwelling types, and changes in weather patterns that are likely to occur in relation to climate change.

The population inputs are used by all NSW Government agencies for planning purposes. The weather data associated with a forecast is taken from a stochastic weather generator simulation based on data from a NARCliM ensemble member in one of the present, near or far future periods. The NARCliM ensemble member and time period represented were varied, with weather reflecting the present, near or far future. Therefore, we were able to examine the consumption forecasts for combinations of populations between 2014/15 and 2024/25 with weather for the present, near future or far future. We therefore undertook three analyses each for the present, near and far-futures:

1. Isolated the effect of climate change on water consumption. Here, population is held at 2019/20 levels and the dwelling type mix uses the population estimates;
2. Isolated the effect of population change on water consumption. Here, population is allowed to vary from 2014/15-2024/25, with a dwelling type mix associated with that population change.
3. Isolated the effect of dwelling type mix. Here, population varies from 2014/15-2024/25 and the dwelling type mix varies between the dwelling type mix estimate, simulations with no single dwellings, and simulations assuming all single dwellings.

However, for the purpose of this paper, we will discuss only (1), the marginal impact of climate change.

The process was repeated for each NARCliM period, GCM and run leading to 12 forecasts altogether.

RESULTS

The results (shown in Figure 1, Table 1 & Table 2) suggest a large variation between the different ensemble members of NARCLiM. However, there is no direct scientific way of selecting one of these forecasts over the other, because the different GCM outputs which lead to the different demand forecasts are all considered equally likely. They are scenarios, rather than members of a probability distribution. This means using a central tendency such as a median or average provides no improvement in prediction accuracy, over that of an arbitary selection of any ensemble member.

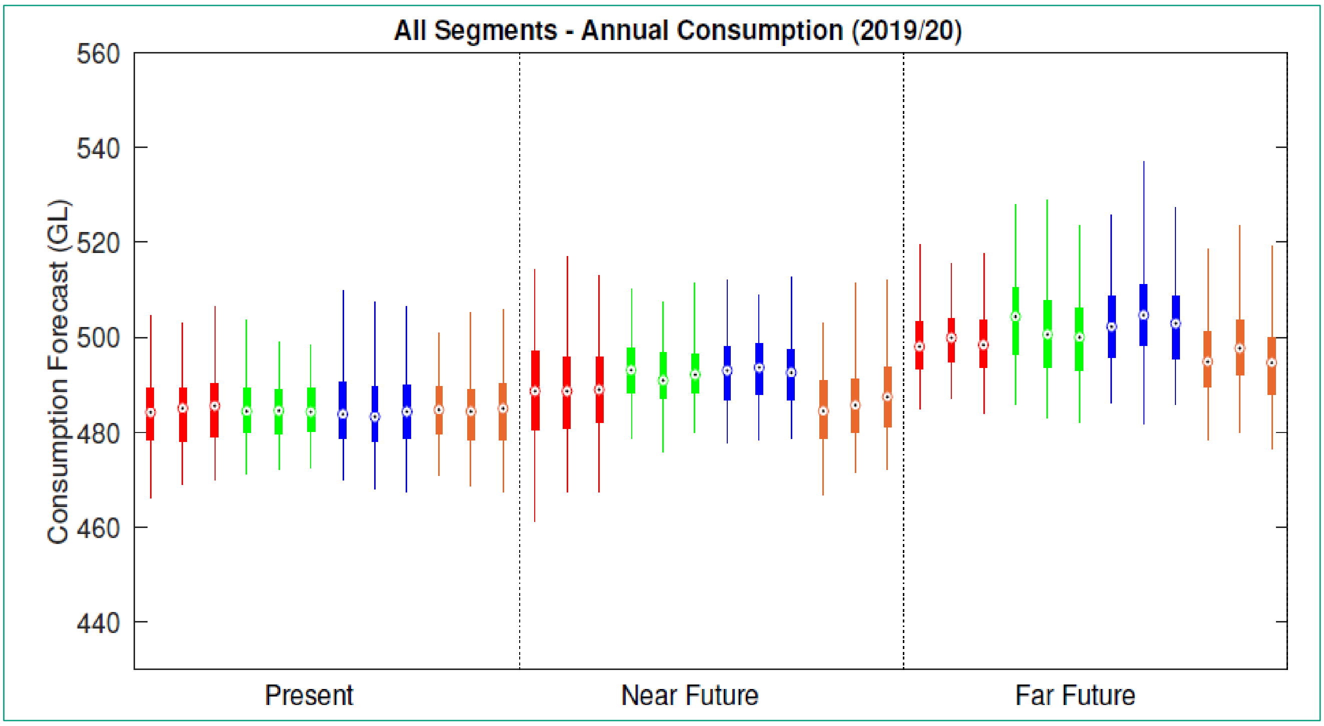

Figure 1: Annual Demand

Red CCMA3.1, Green CSIRO-MK 3.0, Blue ECHAM5, Brown-MIRCO3.2 (reproduced from Barker et al (2018b)

Table 1: Average Annual Total Consumption for 2020-2040 based on 2019/2020

All factors other than climate change kept constant

Model run	Median demand GL	% increase from base year
CCCMA3.1	488.7	0.93
CCCMA3.1	488.7	0.75
CCCMA3.1	489.0	0.72
CSIRO-MK 3.0	493.0	1.79
CSIRO-MK 3.0 2	490.9	1.32
CSIRO-MK 3.0	492.1	1.62
ECHAM5	492.9	1.90
ECHAM5 1	493.6	2.14
ECHAM5	492.5	1.69
MIROC3.2	484.4	-0.06
MIROC3.2	485.6	0.27
MIROC3.2	487.4	0.51

Table 2: Total Annual Consumption for 2060-2080 based on 2019/2020

All factors other than climate change kept constant

Model run	Median demand GL	% increase from base year
CCCMA3.1	498.0	2.86
CCCMA3.1	499.8	3.06
CCCMA3.1	498.4	2.65
CSIRO-MK 3.0	504.3	4.12
CSIRO-MK 3.0 [2]	500.5	3.31
CSIRO-MK 3.0	500.0	3.24
ECHAM5	502.2	3.82
ECHAM5 [1]	504.6	4.42
ECHAM5	502.9	3.85
MIROC3.2	494.9	2.10
MIROC3.2	497.7	2.75
MIROC3.2	494.7	2.00

[1] Suggested for determining investment in infrastructure

[2] Suggested for price determination

The differences between the outputs from the different ensembles is so large that it would be hard, if not impossible to plan for all of them, which makes it necessary to select one.

The solution to this does not lie in the science, but in the way the science is incorporated into decision making. We argue that there is no need to use a single scenario to inform all decisions. Planning against different scenarios depending on the risk profile of the decision involved, is commonly used across government and industry. For example, governments typically plan for high impact situations such as national security or preventing deadly diseases against worst case scenarios, while they plan for things like economic turns against medium term scenarios.

We propose something similar, choosing a projection scenario, based on:

- the impact of error, i.e., the impact of 'getting it wrong'
- potential to respond to an error in terms of capability and speed to respond
- how equitably the impact of error is distributed among stakeholders.

We demonstrate this through the example of the following two decisions.

1. Determining the optimal retail price of water to recommend to IPART.
2. Plan/determining investments in building future infrastructure.

Table 3: Decision framework based on risk profiles

Decision	Direction of error	Impact of error on NSW Govt./SW	Impact of error on customers	Potential/ability & speed to respond	Most appropriate projection
Retail price determination	Over forecast	Loss of revenue		High	Middle case
	Under forecast		High price	High	
Infrastructure/water security planning	Over forecast	Wasted investment		Potential to catch up in time	Worst case
	Under forecast		Service failure/constrain	Slow	

In the case of retail price determination, over forecasting and under forecasting more or less have the same impact. Over forecasting can lead to lower retail prices (as prices are usually set to achieve retail targets) and hence loss of revenue to Sydney Water, whereas under forecasting can lead to a higher cost to consumers. However, the degree of loss or gain is more or less the same in both cases. Therefore, the most appropriate to use would be the ensemble member in the middle of the range. In the case of determining investments in future infrastructure, the consequences of under forecasting, which could lead to supply constraints or shortages, is of graver consequence than wasted investments and building unnecessary excess capacity. Further, responding to under forecasting would be harder as building infrastructure takes time, whereas excess capacity in infrastructure could be absorbed in time as natural growth takes place. It could also be argued that the cost of error would be felt more by consumers than Sydney Water.

Therefore, in the case of determining investments in infrastructure, the ensemble member providing the worst case projection scenario should be used. Since making informed long-term planning decisions is the purpose of the long-term demand forecasting, we recommend ECHAM5 as appropriate for this purpose.

CONCLUSION

This paper set out to quantify the impact of climate change on water demand. We approached the problem by first selecting a Global Climate Model, based on the risk tolerance thresholds of the decision the water-demand forecasts were informing, then generating extreme-weather scenarios based on that Global Model by using a stochastic weather generator, and integrating the weather generator with Sydney Water's Consumption Model. Using this methodology, we recommend that infrastructure development in Sydney should plan for a marginal increase of 2.3% in the near term (up to 2040) and 4.4% in the far term (2060-2080) in demand for water due to climate change.

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THE AUTHORS

Luther Uthayakumaran

Dr Uthayakumaran is attached to Sydney Water and his interests include using science to inform policy and planning decisions.

Frank Spanninks

Mr Spaninks is attached to Sydney Water, where his primary responsibilities include developing water demand forecasts for Sydney. Frank uses a variety of scientific and mathematical techniques including Panel Regression and other econometric modelling techniques. Frank has postgraduate degree in Environmental Economics from Wageningen University in the Netherlands and has published widely in academic journals.

Adrian Barker

Adrian has undergraduate degrees in science and engineering from the University of Sydney and has worked for various organisations including the State Rail Authority. Adrian has a PhD in statistics from at Macquarie University. He joined the CCRC in June 2016, and has been developing stochastic weather generators used to generate probabilistic water consumption forecasts for Sydney Water.

Andrew Pitman

Professor Pitman is director of the ARC Centre of Excellence for Climate Extremes. He is closely affiliated with the World Climate Research Programme, was a Lead Author for Intergovernmental Panel on Climate Change Assessment Reports 3 and 4, and has received several awards including the NSW Scientist of the Year Award (2010).

Jason P. Evans

Professor Evans is attached to the Climate Change Research Centre (UNSW). His interests include water resource issues at the regional scale, particularly the impact on water resources of changes in climate and changes in land-use. He uses various tools to examine the changes including hydrological models, and satellite sensed data.